Flood Hazard Mapping in Malaysia: Case Study Sg. Kelantan river basin

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Abstract:
One of the critical issues in Malaysia, which is mostly reflected in the Sg. Kelantan river basin, is flooding which occurs almost every year. This paper aims to present the result of the study on developing flood maps consisting of flood hazard map, flood evacuation map, and flood risk map. The contents will describe the development, calibration and validation of a flood model for the 100 ARI design flood. Calibration and validation involved comparison between observed and model simulated discharge hydrographs, as well as observed and model simulated flood inundation extents. The use of hydrodynamic model using InfoWorks 1D and 2D techniques and utilizing DEM data from IFSAR significantly improve the results. The hydrodynamic model was applied to reconstruct the recent flood events, as well as to simulate flood inundation due to rainfall events of varying recurrence intervals. The generated flood inundation map helps the preparedness for disaster agency to have proper planning and early evacuation during monsoon flood season. Meanwhile, the flood risk maps will be used as guidance to local government for planning guidelines in line with national development policies and planning principles.

1. Introduction

1.1 Flood disaster statistics

Floods are known as one of the world's most frequent and devastating events including Malaysia (Osti et al., 2008). A substantial amount of the nation's annual expenditure has been allocated to the development of strategies to reduce the effects of flooding. In particular, the impact of flooding in terms of infrastructure damages, human causalities, and long-term economic downturn has been rapidly increasing. This scenario is brought about by the ballooning global population, unsystematic urbanization, and climate change in the form of higher sea levels and more intense cyclones weather systems and precipitation (Sanders, 2007). The damage on agriculture, households, and public utilities caused by floods amounts to billions of dollars each year worldwide, in addition to the loss of human and animal life (Sharma and Priya, 2001).

In Malaysia, floods occur almost every year, especially in areas located in flood plains. These annual flood events have been classified as normal flood which occur during the northeast monsoon season between November and March. Normal flood often inundates the lowland areas in the east coast of Peninsular Malaysia. Meanwhile, major floods occur once every few years, and sometimes, even consecutively, like the 1970 and 1971 flooding in Pekan, Pahang (Chan, 1997). The major flood in Johor (located at the southern part of Peninsular Malaysia) involved more than 110,000 evacuees and 18 casualties. The damages from these disasters amounted to RM 1.5 billion (excluding losses caused by the economic downturn) (Sulaiman, 2007). The flooding in Johor has been classified as “abnormal” as it occurred twice in two months, namely, in December 2006 and January 2007.

Meanwhile, based on Department of Irrigation and Drainage, Malaysia in 2012, about 33,298 km2 or 10.1 percent of the country is prone to flooding. It represent 5.67 million of peoples affected and annual loss more than RM 1 billion. The amounts of losses substantially increase once major flood occurred. As reported, December 2014 flood which hits badly in three states namely Kelantan, Terengganu and Pahang cause more than 500,000 peoples evacuated, 25 casualties and RM2.85 billion losses (not include intangible loss). Malaysia laid on equator and has been categorized humid-tropic region, flash flood almost occurred every month which is in 2018, 450 floods event recorded and 90% is flash flood.

1.2 Purpose of flood hazard mapping

There are various methods to mitigate the damages caused by floods, such as flood prevention, flood protection, flood preparedness, and emergency response. These methods must be objectively approached to reduce the effect of floods and subsequently avoid the loss of human life and damages to infrastructure and agriculture. In Malaysia, flood control has been managed through structural and nonstructural measures. The structural measures concentrated on building dams, reservoirs, embankments, levees, and artificial channels. Major rivers, where building structures are not economically suitable, are widened and deepened through dredging. However, dredging is expensive and resources are not always available.

Another structural measure to protect rivers for short periods is creating a wall out of concrete, bamboo, or wood. For low-lying areas along rivers, a retention pond is built to store floodwater temporarily. The stored water is released only after the river flow returns to its normal level. The retention pond also serves as a multifunctional pond where a certain volume of water is permanently stored. The riverine habitats in the pond could improve the quality of the remaining floodwater, as well as the other habitats in the area. In flood-prone areas where floodwater remains for very long periods, water pumps can be strategically installed along the rivers or flooded areas. These water pumps can either be mobile or permanently installed depending on the volume of floodwater.

While most structural methods attempt to control floods, nonstructural methods largely focus on preventive efforts. Currently, the Department of Irrigation and Drainage (DID) has emphasized the strengthening of a nonstructural approach by introducing more comprehensive solutions to manage flooding. A new Urban Storm Water Management manual (MSMA), published by DID in 2000 (Sulaiman, 2007). This manual emphasizes the management of peak discharge using the concept of "control at source," which means that the time before the runoff water enters the river is lengthened. Therefore, the existing river capacity can accommodate floodwater, eliminating the need for exorbitant-costing structural remedies.

There are others non-structural flood control measures such as flood forecasting and warning system and flood hazard mapping. Conceptually, four stages of flood hazard mapping requires includes flood map, flood hazard map, flood evacuation map and flood risk map. Flood map or flood inundation map defines the location of flood or area of flooding drawn on a map. It draws based on the records of flooding occurred through field observation or satellite imaginaries.

Meanwhile, flood hazard map generated using the hydrodynamic flood model which contains the map of likelihood of the future flood events, which is normally based on Average Recurrence Interval (ARI) of floods. The flood hazard map output includes flood area, flood depth, flood velocity and flood extent. These results will help to generate flood evacuation maps at the particular flooding area. Although, the flood evacuation map subject to time of updated information of evacuation centre and the accessibility of roads during the flood events, this will give guidance on how to act once floods occurred.

The existence of flood hazard map will further enrich with flood risk map. Flood risk is the combination of the probability of a flood event and the potential adverse consequences to human health, the environment and economics activities associated with a flood event. To generate flood risk maps, three components involved which is the value of risk at probability scenarios, the probability of exposure and the vulnerability of objects at probability scenarios. The main target output for flood risk map is to obtain assets information at zone of risk. Flood risk map also used to assist local peoples and governments to develop effective methods of reducing flood-related damages in the community over the long run. It is clear that the least costly and most effective solution is to adopt a preventive approach which emphasizes longer range planning in flood prone areas. Measures such as zoning by-laws, building codes and subdivision regulations can be used to control and direct land use within the flood hazard areas.

2. Flood Mapping

The Department of Irrigation and Drainage, Malaysia responsible to prepare flood map in inundation area at the whole country. Currently, there are 39 flood hazard maps and 3 Flood Risk Maps has been established and this paper will present the methodology for developing the flood maps at Kelantan River Basin (Sg. Kelantan).

2.1 Catchment Background

Kelantan river basin covers an area of about 13,000 km^2 together with its other tributaries, namely Sg. Lebir, Sg. Galas, Sg. Pergau and Sg. Nenggiri. The Kelantan river is approximately 105 km and it includes Lebir and Galas River at Kuala Krai. Kelantan river passes through the several urban areas namely Kuala Krai, Tanah Merah, Pasir Mas and Kota Bharu. Downstream of Kelantan river has a population around 0.5 million which can be in a medium level of population. The river is the principal cause of flooding because it is constricted at its lower reaches. The capacity of the river at downstream area is less than 10,000 m^3/s, therefore flood that exceeds this capacity will overspill the banks and inundation flood water at land surface area and finally moving to the sea. Since 1965, there have been more than 20 floods that exceed the capacity limit. During December 2014 flood events, it was reported that the total damage cost to property, agriculture and infrastructure amounted to more than RM 1 billion, with 319,156 people evacuated and 14 deaths counted. In term of hydrological records, the total rainfall occurs in 10 days about 1898 mm had made this the wettest December on record for the state. This amount is almost 50% of the total annual rainfall (4,000 mm) and a clear indication that the rainfall received during the period was extreme.

2.2 Method to develop flood maps

The study method consists of four stages as below:

Stage 1 – Data preparation and analysis of catchment characteristics

Stage 2 – Hydrological analysis

Stage 3 – Hydrodynamic analysis

Stage 4 – Flood Hazard Map

Stage 5 – Flood Evacuation Map

Stage 6 – Flood Risk Map

2.2.1 Stage 1 – Data preparation and analysis of catchments characteristics.

The study is focused on compilation the availability of documents and pre-existing data that collected from multiple sources including federal and local agencies. There are includes topography and hydrological data, river morphology, spatial data and landuse for current and future scenario. Details of the types of data as follow:

Table 2.1: Details Types of Data for Analysis

No.	Type of Data	Description
1.	Previous study reports	• Hydrological Procedure for Design Rainfall and Design Flow (HP1 (2010), HP11(1976), HP27(2010) • DID Manual (Flood Management) (2008) • Urban Storm Water Management Manual for Malaysia (2010) • Flood Hazard Mapping, FEMA (2015) • Handbook on Good Practices for Flood Mapping in Europe (2007) • Integrated Flood Risk Analysis and Management Methodologies – Review of Flood Hazard Mapping (2008)
2.	Flooding reports	Flood reports 2000 to 2015
3.	Rainfall, water level and streamflow, evaporation records	Hydrological data between 2000 to 2015
4.	Tidal information	Kuala Kelantan tidal gauge
5.	Flooding extents and lists	Flood extents for extreme flood event 2011, 2012, 2013, 2014
6.	River cross-section	Various interval between 400, 500, 1000 meter
7.	Topographic maps	20m- interval contour line and IFSAR
8.	Soil Map	Hydrological Soil Group and soil type
9.	Landuse map	Current land use and future landuse in 2020
10.	Satellite imaginaries	Archive data 2000 to 2013
11.	On-site observe data collection	Flood mark and water assets
12.	Climate Change Factor	Technical guide-Estimation of Future Design Rainstorm under the Climate Scenario in Peninsular Malaysia; National Hydraulic Institute Malaysia (NAHRIM)

For the purpose to delineate the catchment and sub-catchment boundary and slope, DEM data at 20m interval and IFSAR data has been used. Analysis to merge all data has been carry out using ArcGIS software. The IFSAR data was merged with the interpolated DEM points result from contour line for the area is not covered by IFSAR. There are 13's

Ground Control Point (GCP) stations used for model comparison using RMSE to measure the accuracy. It was found DEM dataset is 4.5 meter more lower compare to IFSAR. Therefore, raster adjustment has been done in order match IFSAR data.

In term of river cross section, Sg. Kelantan carry out recent survey and provide cross section data at 400, 500 or 1000 meter interval subject to the river morphology and the existence of river facilities such as bridges, water intake, weir, pump house on the others.

2.2.2 Stage 2 – Hydrological analysis

The purpose of carrying out the hydrological analysis is to investigate in detail the response of the catchment to rainfall and to derive the design flood hydrographs with reasonable accuracy using an appropriate rainfall-runoff model from the rainfall data. This design flood hydrograph will be routed through a model of river channels in order to evaluate the conveyance capacity of the river concerned. The resulting flows from Sg. Kelantan will then be used in the derivation of flood inundation area.

All rainfall, water level, streamflow and rating curve data had been obtained from the Water Resources Management and Hydrology Division of DID. For the rainfall data set, a quality assessment was conducted by plotting double mass curves for all stations and identifying stations which are not suitable for analysis. The double mass plot/curve is commonly carried out to verify the integrity and consistency of the rain gauge data recordings. As for the water level and streamflow data, a yearly plot was conducted to assess and identify large gaps of missing data.

The hydrological modeling was completed by utilizing the InfoWorks ICM Software, using SCS Synthetic Unit Hydrograph Method. This was then calibrated with 8 extreme rainfall events. A flood frequency analysis of the streamflow data had also been completed. For the purposes of this Study, an adopted rainfall temporal pattern was used as Hydrological Procedure No. 1 (HP1). The design rainfalls obtained were then applied onto the calibrated rainfall-runoff model in order to produce design flood hydrographs of various return periods and durations for present and future land use conditions. These hydrographs would later serve as input boundary conditions of the hydraulic model.

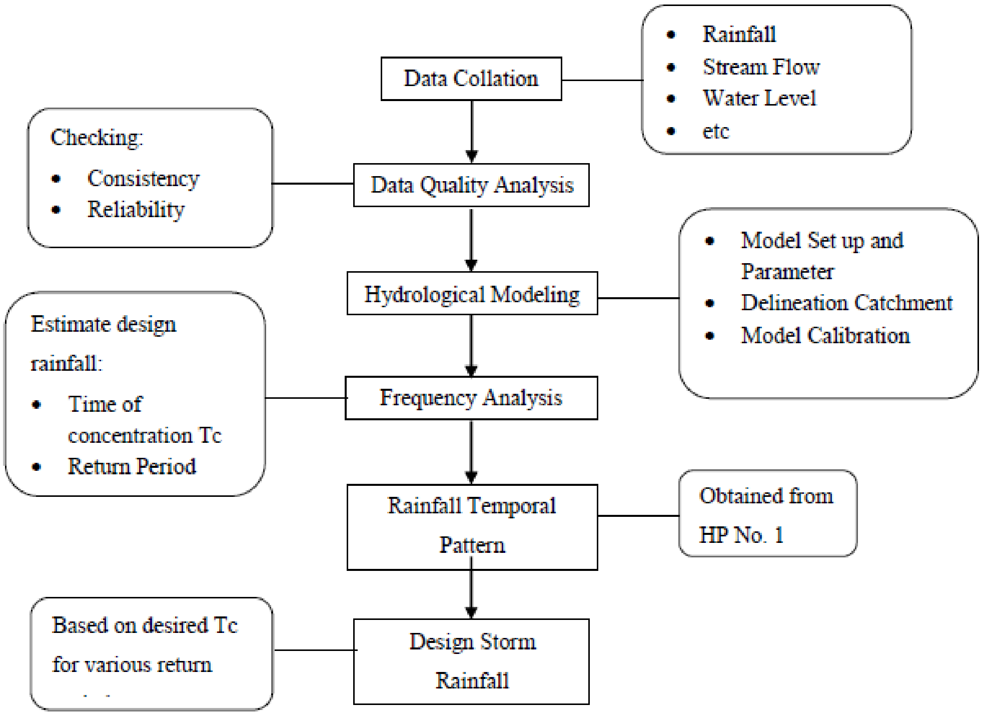


Figure 2.1: Flow diagram of the Hydrological Analysis

2.2.3 Stage 3 – Hydraulic and Hydrodynamic analysis

The hydrodynamic analysis in this study was carried out to evaluate the capacity and the conveyance of the existing Sg. Kelantan river system for various input hydrographs obtained from the hydrological analysis. Hence, the main purposes for the hydraulic analysis are:

- To obtain the design discharges of Sg. Kelantan river system using the input flood hydrographs at various Average Recurrence Interval (ARI) from the Rainfall Runoff (RR) model.
- To obtain the design water surface profiles along the rivers

The flood simulation modeling software used in this study is InfoWorks Integrated Catchments Model (ICM). In preparing the flood maps and deciding the best flood mitigation solution, integrated use of one-dimensional (1D) and two-dimensional (2D) hydrodynamic models is utilised as this can simulate the river and flood plain interaction. InfoWorks ICM enables hydraulics and hydrology of natural and man-made environments to be incorporated into a single model. "The 2D engine used in InfoWorks ICM is based on the procedures describes in Alcrudo and Mulet-Marti (2005). The shallow water equations (SWE), that is, the depth-average version of the Navier – Stokes equations, are used for the mathematical representation of the 2D flow. The hydrological output data and the cross-sections derived from digital terrain model were used in the hydraulic analysis. The SWE assume that the flow is predominantly horizontal and that the variation of the velocity over the vertical coordinate can be neglected". (ICM Help, 2015). Bridges, low weirs and river confluences along the river were also used as inputs in the model to simulate the real conditions. The hydraulic model was also calibrated to the 2013 flood event, and subsequently validated to the 2011, 2012, 2013 and 2014 events.

"The 2D mesh is generated using Shewchuk Triangle meshing functionality. Heights at the vertices of the generated mesh elements are calculated by interpolation from a specified Ground Model. A single mesh element may be made up of more than one triangle, if a triangle has an area less than the minimum element area specified for the 2D Zone. Triangles will be aggregated with adjacent triangles until the minimum area is met. The ground level for a mesh element is calculated by sampling the ground model within 2D triangles making up the element and then taking the average of the sample point levels". (ICM Help, 2015)

"The number of sample points for each triangle is determined by subdividing the triangle until the minimum element area or, (when using a Gridded Ground Model), the ground resolution model resolution is reached. The sample points are the centroids of the resulting triangles. If a triangle is smaller than the minimum element area or ground model resolution, the centroid of the triangle will be the only point sampled. The same method is used when recalculating mesh element ground levels by resampling elevations from a different model." (ICM Help, 2015).

In the model setup for hydrodynamics analysis, the basic formulae used in 1D Hydrodynamics Models are based on the one-dimensional unsteady state gradually varies flow equations, which are termed as "the St. Venant Equations". In the modeling of floods, flows often take short cuts through flood plains where the 1D description may become quite inaccurate. For this reason, the 2D shallow water equations are introduced. The hydraulic analysis will be done using the combination of 1D and 2D hydrodynamic modeling. The basic data required are river cross-section, structural details and digital terrain model. The setting up the basic 1D hydrodynamic modeling uses the river cross-section surveys data. For 2D floodplain modeling, comprehensive dot grid with grid spacing of digital terrain model namely IFSAR will be used instead.

The following assumptions used in this study:

i. Design flood hydrographs – All the inflow hydrographs into the Sg. Kelantan river system were obtained from the hydrographs derived the rainfall - runoff model. Two catchments conditions were evaluated: the present and future land use conditions:
ii. Since the survey cross-sections were limited within the river channels, floodplains that have substantial influence on the flood levels and flow discharges could not be ignored in the simulation. The floodplains located on both riverbanks and the widths

of the floodplains were based on IFSAR survey, aerial photographs and flood maps available from the JPS records.

iii. Channel and Flood Plain Roughness – The channel roughness n of 0.035 and 0.05-0.07 were assumed for all main river channels and floodplains respectively from the model calibration and validation results.

iv. Tide Levels – Hydrodynamics modeling using Infoworks (ICM) model and for reaches under tidal influences required tidal information at the river mouth. Tidal data was obtained from the Royal Malaysia Navy at Kuala Kelantan secondary port;

v. River Mouth Tail Water Level – the Mean Higher High Water (MHHW) was used as the design tail water level for floods of various ARIs due to its fairly frequent occurrences as compared to the Highest Astronomical Tide (HAT)

vi. River Mouth Tail Water Level for Critical Velocity – for evaluating bank erosion potential where the critical parameter is the flow velocity, the Mean Lower Low Water (MLLW) was used as the design tail water level at the river mouth

vii. In all cases, tide cycle was adopted as the tailwater at the rivermouth instead of water level. Possible rise in the sea level due to storm surge was considered to be negligible and hence ignored in the analysis. Other causes such as greenhouse effect that may increase the sea level etc. were also ignored; and

viii. It was assumed that rainstorm of the same ARI and duration occurred simultaneously over the whole river basin for all simulations.

ix. The critical storm duration has been determined to be 3 and 5 days.

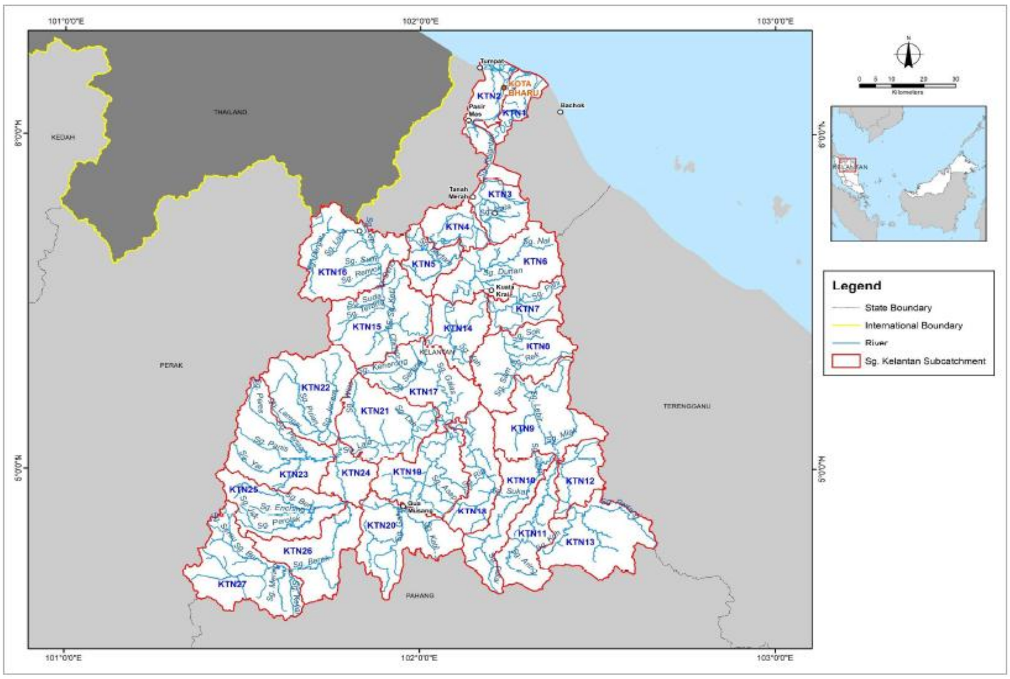


Figure 2.2: Sub-catchments division of Sg. Kelantan

2.2.4 Stage 4 – Flood Hazard Maps

The generation flood hazard maps for Sg. Kelantan based on flood hazard degree. The flood hazard maps include the details of flood extent with flood depth classification and the Point of Interest (POI). Table 2.2 shows the classification of flood hazard degree.

Table 2.2: Classification of flood hazard degree

Degree of Flood Hazard	**Flood Depth (m)**	**Desciption**
Low	< 0.5	**Caution** "Caution: Flood zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous** "Danger: Flood Zone with deep or fast flowing water". Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first floor evacuate.
High	1.2 – 2.5	**Dangerous for all (Level 1)** "Extreme Danger: Flood zone with deep fast flowing water: Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.
Very High	➢ 2.5	**Dangerous for all (Level 2)** "Extreme Danger: Flood zone with deep fast flowing water: Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Flood hazard maps were produced based on 5, 10, 20, 50 and 100-year ARI's at the scale of 1:25,000 for present and future land use conditions. The flood hazard maps for the specified ARIs must clearly indicate:

a) Flood depth; and
b) Flood extent

The flood depths were denoted by the colour scheme below;

Colour	Flood Depth	Colour Name	R	G	B
	0 – 0.5 m	Sodalite Blue	190	232	255
	0.5 – 1.2 m	Big Sky Blue	0	197	255
	Above 1.2 m	Lapis Lazuli	0	92	230

- The hardcopy of Size : A1 printed maps
- Scale: 1:25,000
- The flood extent shall be overlaid on top of the cadastral maps, river network, transportation network and flood evacuations centres' locations
- The flood hazard map clearly mark the major towns, flooded areas and point of interest.

2.2.5 Stage 5 – Flood Evacuation Maps

The flood evacuation maps for the Sg. Kelantan river basin were drawn based on the flood hazard maps of 100 year ARI for present and future land use conditions. Among the important details included in the maps are:

a) Flood extent (with flood depth classification)
b) Location of primary evacuation centres
c) Maximum capacity of the evacuation centres
d) Major towns
e) Emergency contact numbers
f) Transportation network
g) Point of Interest (POI)
h) Size of inundation area
i) Estimated number of people affected

The flood evacuation centres are denoted by the colour scheme below:

Colour	Category	Colour Name	R	G	B
	Flood evacuation centre	Mars Red	255	0	0

The standards as set by DID for the production of flood evacuation maps are:

- Size : A1 printed maps
- Scale: 1:25,000
- The flood extent shall be overlaid on top of the cadastral maps, river network, transportation network and flood evacuations centres' locations
- The flood evacuation map shall clearly mark the major towns, flooded areas and point of interest.

2.2.4 Stage 6 – Flood Risk Maps

In development flood risk maps, flood damage assessment is crucial to obtain the losses value once flood occurs. The flood damage will include direct and indirect tangible damages. Among the important details included in the maps are;

a) Flood risk zone
b) Flood extent
c) Location of primary evacuation centres
d) Major Towns
e) Transportation Network
f) Point of Interest (POI)

The flood risk zones are denoted by the colour scheme below:

Colour	Flood Risk Class	Colour Name	R	G	B
	Very Low Risk	Grey	178	178	178
	Low Risk	Sky Blue	135	206	235
	Medium Risk	Yellow Green	154	205	50
	High Risk	Orange	255	170	0
	Very High Risk	Red	255	0	0

The standards as set by DID for the production of flood risk maps are:

- Size : A1 printed maps
- Scale: 1:25,000
- The flood extent shall be overlaid on top of the cadastral maps, river network, transportation network and flood evacuations centres' locations
- The flood risk map shall clearly mark the major towns, flooded areas and point of interest.

Development of Risk index

Flood risk is a measure of the statistical probability of flooding combined with the adverse consequences of the flooding. The practical determination of future flood risk is made up of four major components: (i) the probability of flooding (ii) the exposure of the receptors-at-risk to different flood characteristics (iii) the value of receptors-at-risk and (iv) the vulnerability of these receptors-at-risk. This brief information outlines the procedure on how the flood risk can be computed and mapped out using GIS software.

In its most general form, flood risk can be computed using the following formula:

$$\mathrm{R} = \sum_{i=1}^{n} \frac{1}{i} D_i$$

Where,

R = Flood Risk
i = Return Period (2- , 5-, 10-, 20-, 50- and 100-year ARIs)
D_i = Damage for Return Period i

The computation and mapping of flood risk involves 6 steps. For each flooded pixel (location), say 100m x 100m, the following computational steps can be adopted in order to produce the flood risk map.

i. Step 1 – Determine the unit damage rates that are relevant for each pixel.
   The unit damage rates were calculated based on applicable rates covered under 11 different catagories and their applications depend on the relevant characteristics and features of each pixel.
ii. Step 2 – For each return period (2-, 5-, 10-, 20- and 100-year ARIs) multiply the computed unit damage rates with the relevant damage factors to produce the estimated damage for each pixel.
   The damage factors to be applied shall include flood depth, duration and strata (rural and urban). In this sense the application of the appropriate factors depends on the flood characteristics / severity.
iii. Step 3 – Multiply the estimated flood damage for each return period (2-, 5-, 10-, 20-, 50-, and 100-year ARIs with the probability occurrence.
   The probability occurrence is, equal to 1/Return Period. For each return period, multiply the probability with the corresponding estimated flood damage.
iv. Step 4 – Sum the results of the multiplication in step 3 to produce the weighted average damage for each pixel.
   Sum the product of probability of occurrence and estimated flood damage computed in Step 3 to produce the weighted average damage.
v. Step 5 – Classify the estimated damage into several flood risk classes.
   Five risk classes are proposed : Very Low, Low, Medium, High and Very High.
vi. Step 6 – Colour-code the classes to produce flood risk map.
   Produce flood risk map by colour-coding the risk classes into 5 catagories. The proposed ranges to be adopted are as described in step 5.
   In general, the flood risk map that eventually be produced provides a graphical representation of the magnitude of potential impact of floods by combining the probability of occurrence and size of dmage.

The explanation in flood risk category is being described in Table 2.3 below.

Table 2.3: Flood risk classification

Risk Class	Index Range	Representative Description of Typical Areas
Very Low	< 50	• Oil palm or rubber land that are infrequently and less severely flooded • Any type of land use with very low probablity of occurenceand very low damage
Low	51-1,000	• Rice fields or sparsely populated rural areas that may be subjected to frequent, but low severity flood • Any type of land use with potentially moderate damage when flood occurs
Moderate	1,001-5,000	• Moderately dense rural residential areas with good infrastructure that are subjected to frequent floods • Any type of land use with potentially moderate damage when flood occurs
High	5,001 – 25,000	• Densely populated areas with good infrastructure that are subjected to frequent floods. • Any built up area with potentially high damage when flood occurs.
Very High	>25,000	• Densely populated urban areas with plenty of commercial/industrial establishments and served by extensive infrastructure with frequent flooding of various magnitude and occasionally very severe flood • Any built up area with potentially very high damage when flood occurs

Note: Flood risk range is developed based on 2-, 5-, 10-, 20-, 50- and 100-year ARIs floods in the Sg. Kelantan river basin.

3. Results and Application of Flood Hazard Map

3.1 Hydrodynamic Simulation

The hydrodynamic (HD) model was calibrated by comparing model simulation results of the existing conditions with measured data. In this case, the December 2013 Kelantan flood event was chosen for the model calibration. The model parameters were then adjusted to give the best estimates. The HD model was calibrated using measured water level at Sg. Nenggiri at Jambatan Kusial stations. Predicted tidal levels time series at the river mouth of Sg. Kelantan tidak stations served as the downstream boundary condition. Figure 3.1 shows the comparison between simulated and measured river levels at recorded water level station for December 2013 flood.

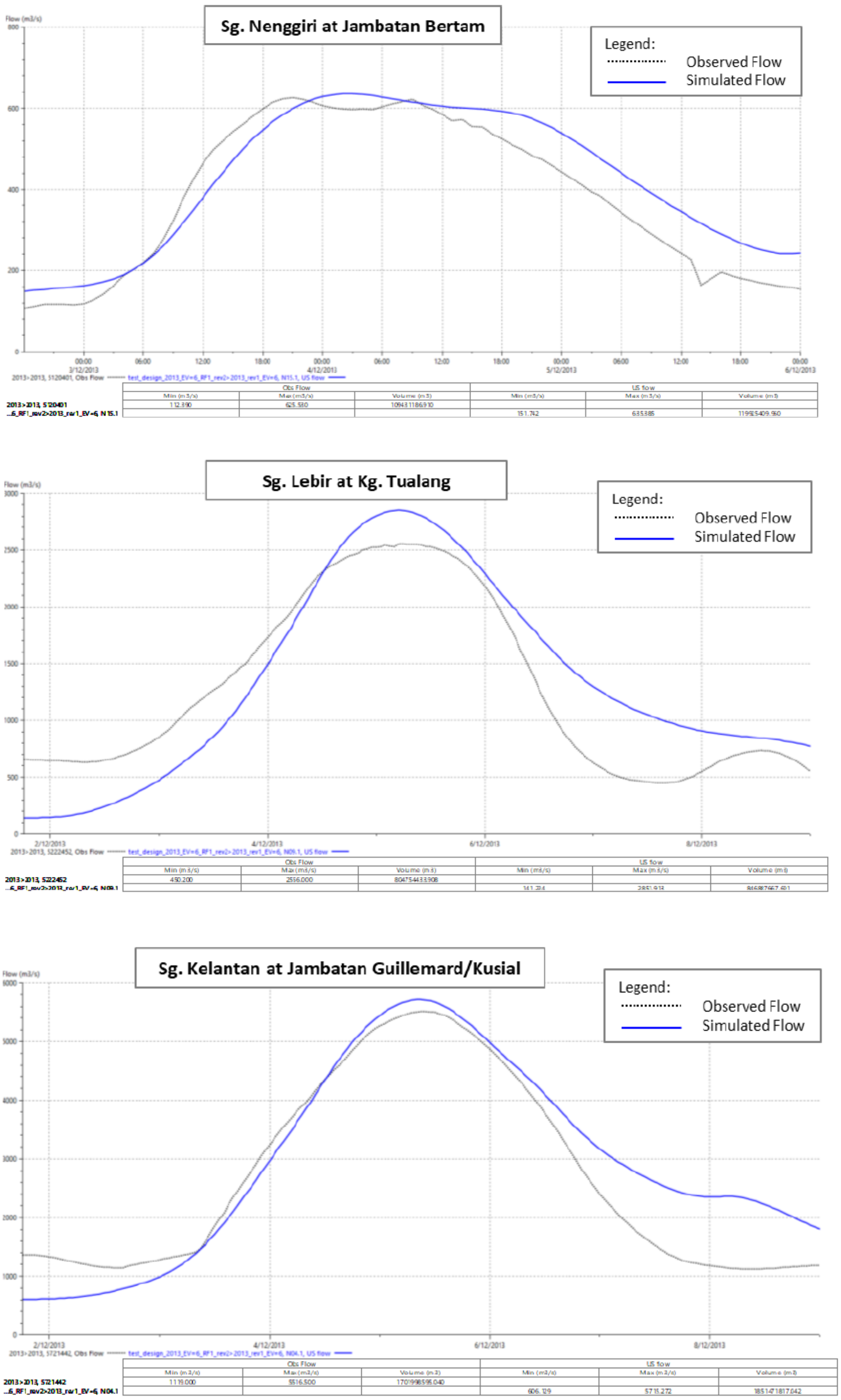
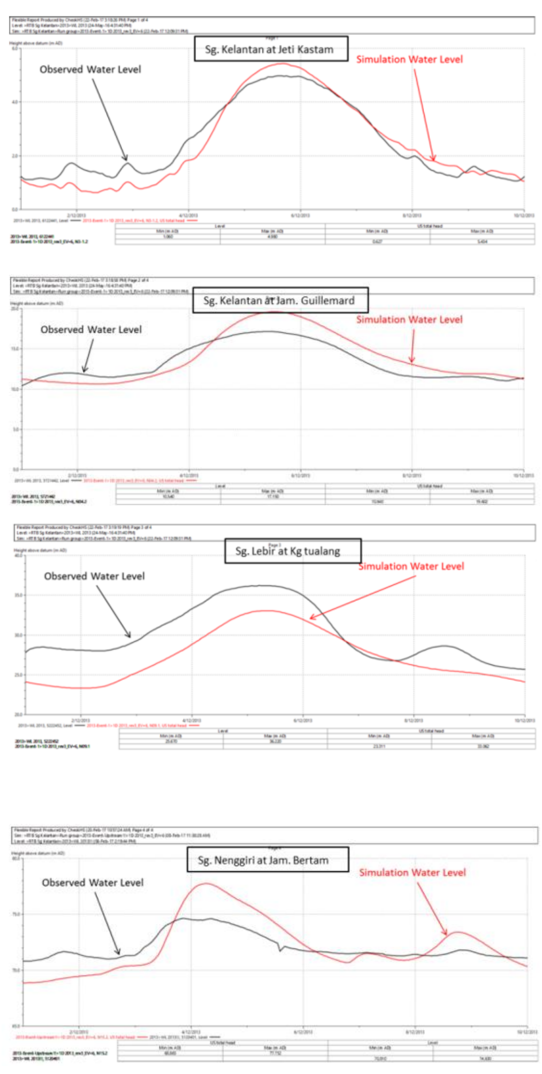
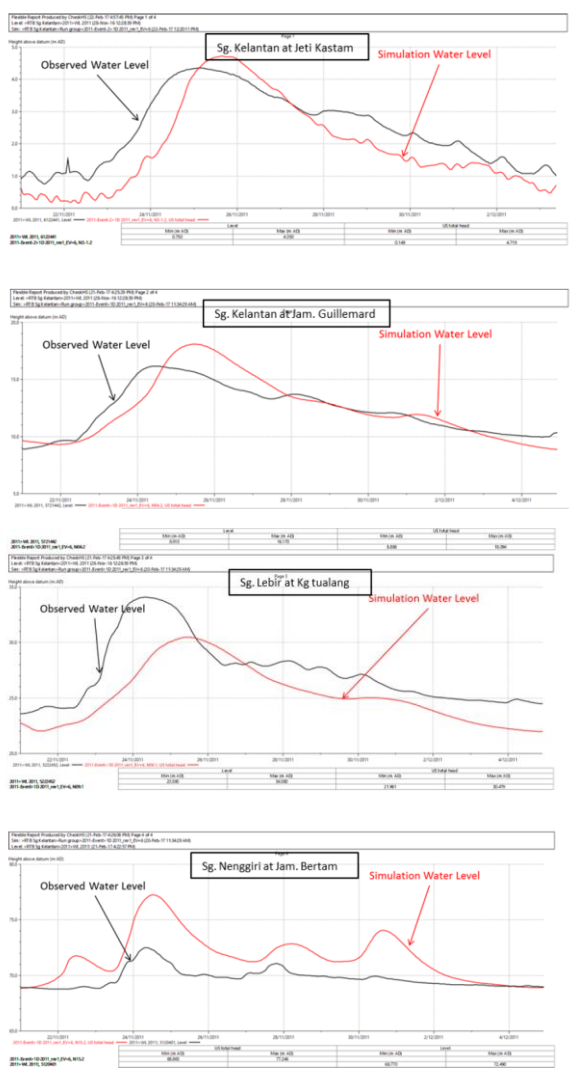


Figure 3.1: Calibration hydrograph for hydrodynamics analysis

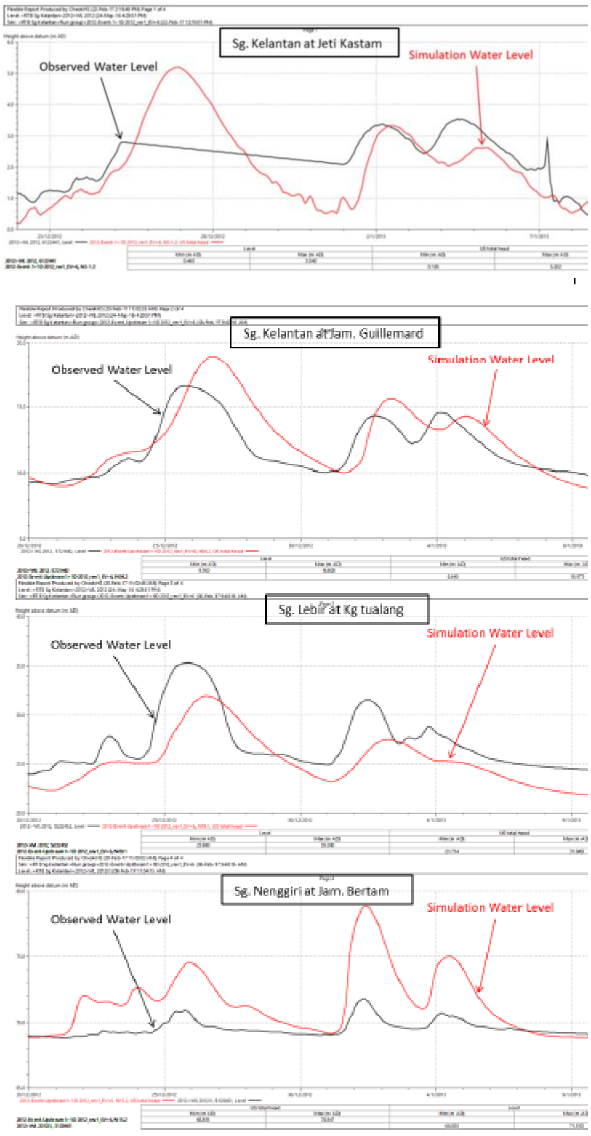
The hydrodynamic model was then, being validated using measured water level data for different flood records. In this case, data from 1st to 9th Dec 2013, data 21st Nov to 2nd Dec 2011, data 20th Dec 2012 to 9th Jan 2013 and data 22nd Dec 2014 to 6th Jan 2015 were used for model validation.

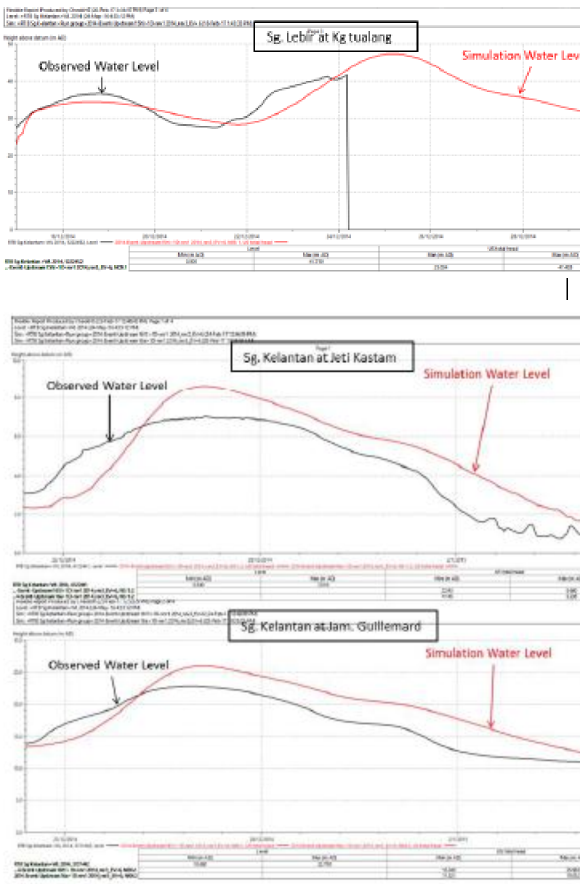




1st to 9th December 2013 flood events	21st November to 2nd December 2011 flood events

Figure 3.2: Validation hydrographs for December 2013 and December 2011 flood events





20th December 2012 to 9th January 2013 flood events	22nd December 2014 to 6th January 2015 flood events

Figure 3.3: Validation hydrographs for January 2013 and December 2014 flood events

From the calibration and validation analysis, it shows the model give reasonable results particularly for the hydrograph peak but less accurate for the time of peak.

3.2 Flood Maps

The calibrated hydrodynamic model was used to simulate various scenario of flood condition at multiple design flood condition which consists of 2, 5, 10, 20, 50 and 100 ARI. The flood maps for Sg. Kelantan river basin was divided to 17 box plot to represent appropriate scale of map area. The flood hazard map, flood evacuation map and flood risk map for 100 ARI current conditions at H3 Grid location presented in Figure 3.4 to Figure 3.6. Other maps for 100ARI condition at current and future condition were include in Appendixes;

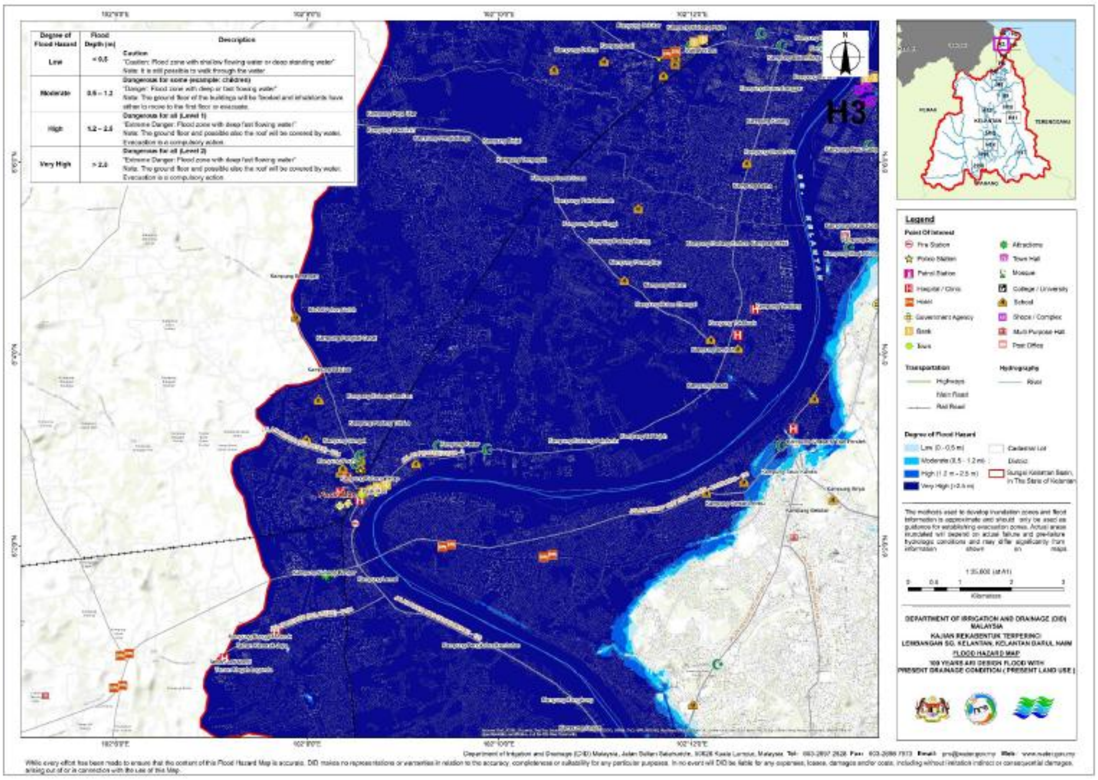
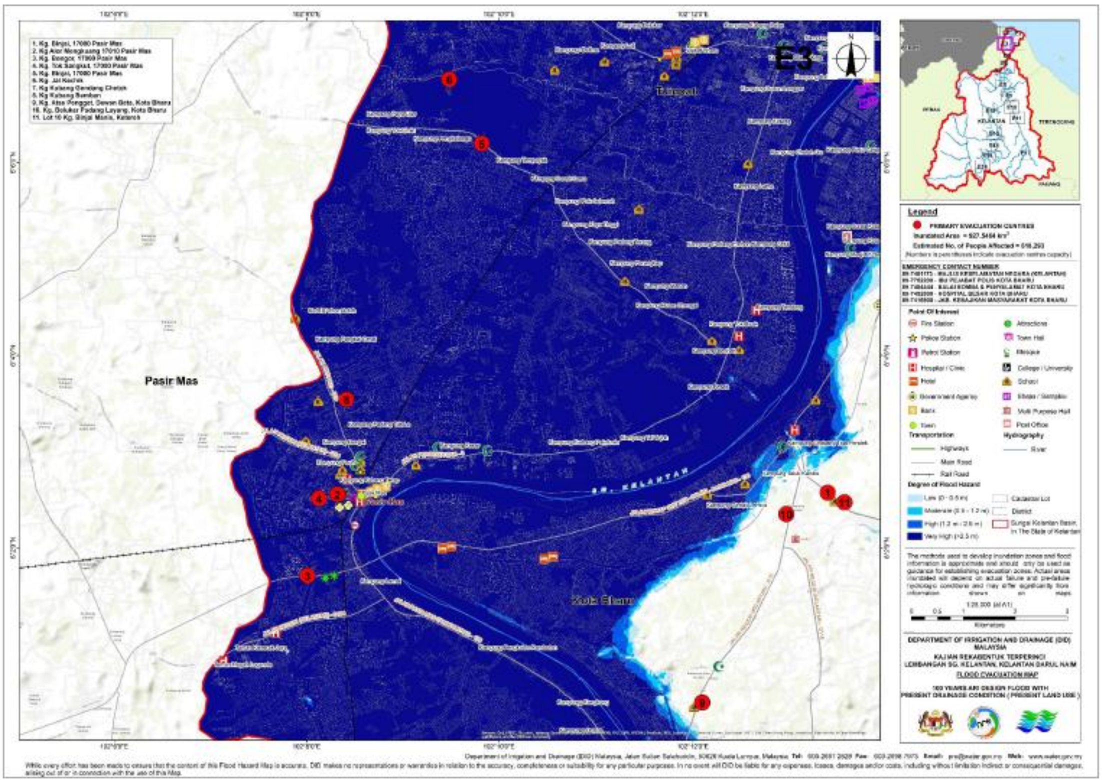


Figure 3.4: Flood Hazard Map for 100 Years ARI Design Flood with Present Drainage Condition (Present Land Use) at H3 Grid Location



(b) Figure 3.5: Flood Evacuation Map for 100 Years ARI Design Flood with Present Drainage Condition (Present Land Use) at E3 Grid Location

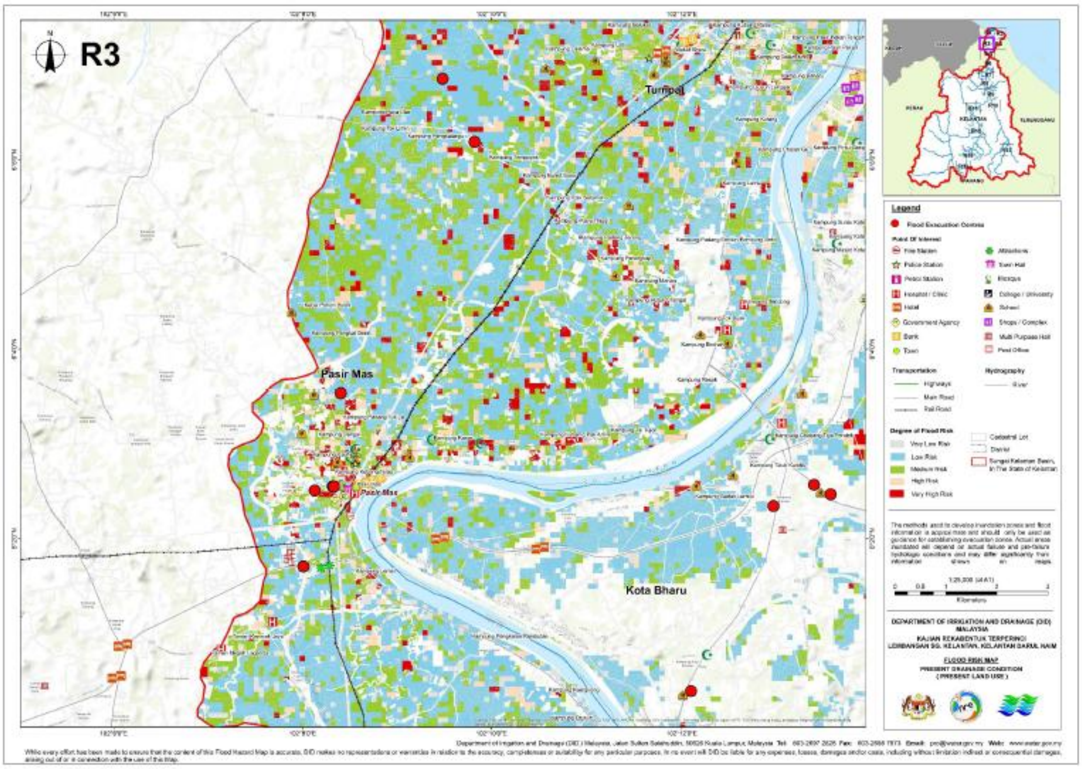


Figure 3.6: Flood Risk Map for 100 Years ARI Design Flood with Present Drainage

4. Challenges and Recommendations

4.1 Lesson Learned and Challenges

It can be deduce that the coverage of the Study is very comprehensive and detailed. Besides the extensive coverage, the challenges confronting this Study are further compounded by (i) time constraints (ii) technical challenges (iii) data availability as further details below;

a. Insufficient data

The availability of historical and real-time meteo-hydrological data is critical to the success of this Study. With insufficient data, the model can only be calibrated and validated for hydrological analysis only. For example, all the hydrographs stations in the Study Area are located in the upstream reach, whereas the critical areas that are being flooded are located in the downstream reaches. The water level and discharge station is located Kuala Krai. Therefore, there is insufficient observed water level and discharges data needed for model calibration in the downstream reach. In this case, the parameter set for the downstream reach was extrapolated from the hydrograph from the upstream reach.

b. Digital Elevation Model Data

One of the major concerns of this Study is related to the accuracy of the DEM data. It should be noted that the DEM forms the backbone of the hydrological model, whereby the level of accuracy of the DEM will have a direct linkage to the accuracy of the flood hazard maps that are produced. Even though IFSAR data available in this Study, the accuracies of 2D simulation particularly for depth of water at inundation area not very accurate. The need to use higher accuracies DEM data such LiDAR will improve the accuracy and reliability of flood maps. The existing LiDAR data coverage is minimal, with coverage limited to only approximately 10 percent of the whole river system. As a result, IFSAR data was used to cover the potential flooded area. This will inadvertently degrade the accuracy of the simulated results.

As the Study area is relatively flat in the downstream floodplain, a slight change in the elevation of the flood level will invoke a substantial change in the area coverage of the flood. However, the differences of flood coverage for different ARIs are not so obvious in the upstream part due to the area being surrounded by hills.

c. River Cross-Section Survey Data

The river survey data made available for this Study was sufficient to complete the modeling setup. However, for the certain river stretch, interpolated dataset from IFSAR data was used to set up the hydraulic model. Smaller interval cross-section data will result more accurate presentation of actual ground elevation to be well match with IFSAR data. The amount of water spill to the flood plain is much depends on the chainage intervals of the river and the accuracy of the IFSAR data.

d. Data collection

Data collection is therefore needed to enhance existing body of knowledge about previous flood events. The collection pre-existing information, which may seem to be a very simple task, however, actually it was very time-consuming, costly and laborious. Furthermore, this information exists in various forms, standards and data format and also kept by various private and public agencies. Having collated all the existing information, it must also identify if there is any data gap. If there is, then dummy dataset has to be created. This will involve determining the extent of the data required, collection activities, cost estimate and time frame or scheduling of the data collection.

e. Computation time of 2D modeling

A practical computation time is derived by compromising accuracy. Factors affecting computation time include:

- The specification of workstation
- Accuracy of processed Digital Terrain Model
- Mesh Size during development of ground model
- Representation of infrastructure ground model

f. Study case for Flood Risk Index

The categorization of flood risk values into five risk classes requires end values (range) to be determined from a large set of data points (pixels of weighted average damage). In order to ensure that the range for all risk classes is valid, the set of data points must not only represent a variety of return periods, but also derived from river basins that cover all land uses. This is especially pertinent since the end values obtained in this Study will be used as a basis for classification of flood risk for the entire country. The end values (range) must be determined using a rich enough data set that covers all land uses of interest. Unfortunately, the Sg. Kelantan river basin does not cover sufficiently diverse land uses that allows for a determination of end values for national application.

4.2 Recommendation

a. Calculation of Risk Index by Incorporating Shorter Return Period

The initial return period considered for risk index calculation did not include the 2-year return period. In the course of conducting the study, it was considered wise to include 2-year return period in flood risk calculation. This is because relatively small floods (but with relatively high probability of occurrence) do inflict some real damage that must be incorporated in the risk index calculation. Hence, omitting 2-year period flood events would undermine the risk index in a systematic manner.

The risk index is made up of two components i.e. the magnitude of damage and the corresponding probability of occurrence. The second component (probability of occurrence) may be viewed as the ‘weight’ attached to the corresponding flood damage for each return period. In this sense, it is unwise not to include the 2-year return period since it has the highest weight of 0.5, followed by 0.2 for 5-year return period, 0.1 for 10-year return period and so on.

b. Periodic Updating of Flood Risk index

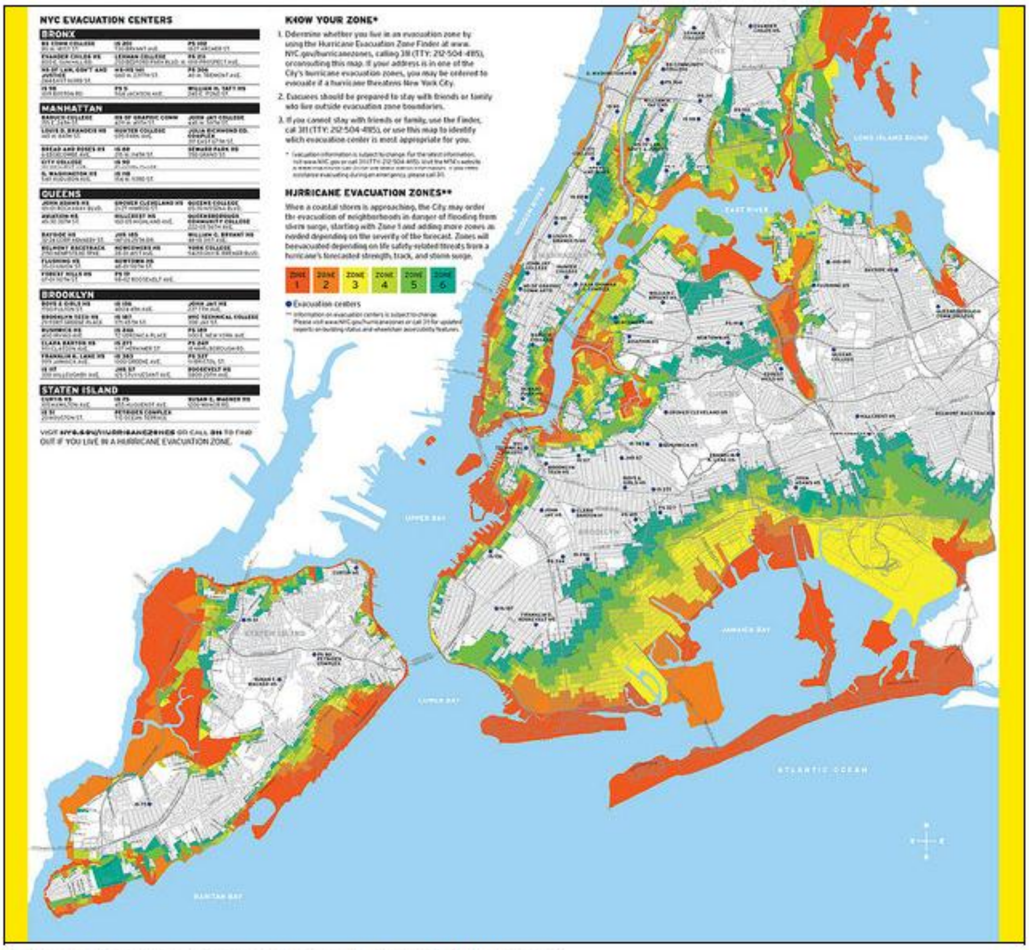
This study recommends that the flood risk index be updated on a periodic basis. Periodic update is necessary to ensure that the flood risk maps reflect the continually changing land uses, economic development status, property values, cost of operations, construction costs and general price levels. Since resources and fund have to allocated for updating purposes, it is recommended that updating interval one every five years is implemented. A shorter between updates maybe costly (or even unnecessary, given that some of the updating factors evolve gradually over time) while too long an interval may render the flood risk map significantly outdated. A five year interval appears to be an optimal balance between the need for the most current flood risk map and the cost (both financial and human resources) of conducting update.

c. Flood Evacuation Zones Maps

This study also recommends that flood evacuation zone maps should be adopted in upcoming studies. Flood evacuation zones map is a zonal map that is produced based on combination of flood extent boundaries for various ARIs. The zone are proposed to be six (6) Zone category according to the degree of flood risk (highest to lower risk) based on the flood recurrence interval. Figure 4.1 and Table 4.1 shows a good example practices in the United States of America that can applies in generating flood evacuation zone map for the usage of the response agencies and residents to plan for evacuation.

Table 4.1: Example of Evacuation Guidelines

Evacuation Zones	Probability of Flood Occurrence (ARI)	Description	Evacuation Plan
Zone 1	<2yr ARI	- Up to average 2 years ARI flood extent - Flood at least once in 2 years	Residents in Zone 1 must evacuate
Zone 2	2yr - 5yr ARI	- Up to average 5 years ARI flood extent - Flood at least once in 2 to 5 years	Residents in Zone 1 and Zone 2 must evacuate
Zone 3	5yr – 10yr ARI	- Up to average 10 years ARI flood extent - Flood at least once in 5 to 10 years	Residents in Zone 1, Zone 2 and Zone 3 must evacuate
Zone 4	10yr – 20yr ARI	- Up to average 20 years ARI flood extent - Flood at least once in 10 to 20 years	Residents in Zone 1, Zone 2, Zone 3 and Zone 4 must evacuate
Zone 5	20yr – 50yr ARI	- Up to average 50 years ARI flood extent - Flood at least once in 20 to 50 years	Residents in Zone 1, Zone 2, Zone 3, Zone 4 and Zone 5 must evacuate
Zone 6	50yr – 100yr ARI	- Up to possible maximum flood extent - Flood at least once in 50 to 100 years	Residents in all zones must evacuate



Source: http://www1.nyc.gov (New York City Official Website)

Figure 4.1: Example of New York City Evacaution Zones Map

d. Real-time Flood Hazard Maps

The hydrodynamic model shall further enhance for use of flood forecasting and warning purposes. It can be done through integration with real-time hydrological data such as rainfall and water level. The simulation result will depend on the computation time and the availability of observe hydrological data. Further, output of flood hazard map for the Point of Interest (POI) shall have more accurate classification. The POI can be divided to three groups which are Key Forecast Point, Forecast Point and Target Point. Details for each group show in Table 4.2.

Table 4.2: The classification of Point of Interest

Point of Interest	Description
Key Forecast Point	The main forecast point that means the location that have water level station or streamflow station with the water level threshold
Forecast Point	The location that have the cross sections with the water level threshold.
Target Point	The forecast location in the flood plain with threshold base on flood depth

5. Conclusion

This study was conducted after the extreme flood in December 2014 with the objective to assess the possible impact of risk due to flood. Flood risk with the combination of the probability of a flood event and the potential adverse consequences to human health, the environment economics activities associated with a flood. In line with the Integrated Flood Management (IFM) concept, the structural and non-structural measures are needed to manage flood risk. The technique used in this study is generally acceptable and shall be further enhanced using up-to-date methods and to adopt few recommendation in this paper. In order to expand the similar study for others river basin, involvement from research agencies and university were encourages.

6. References

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APPENDIXES

Figures consist of Flood Hazard Maps, Flood Evacuation Maps and Flood Risk Maps for Kelantan river basin for 100 ARI design flood.

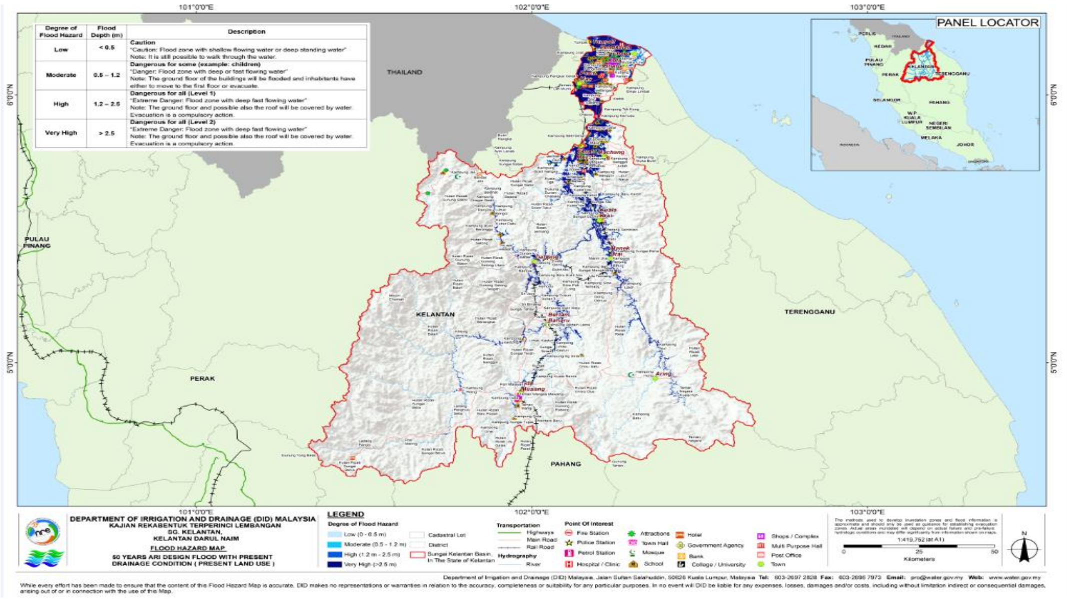

Figure 1: Flood Hazard Map for 100 Years ARI Design Flood with Present Drainage Condition (Present Land Use)

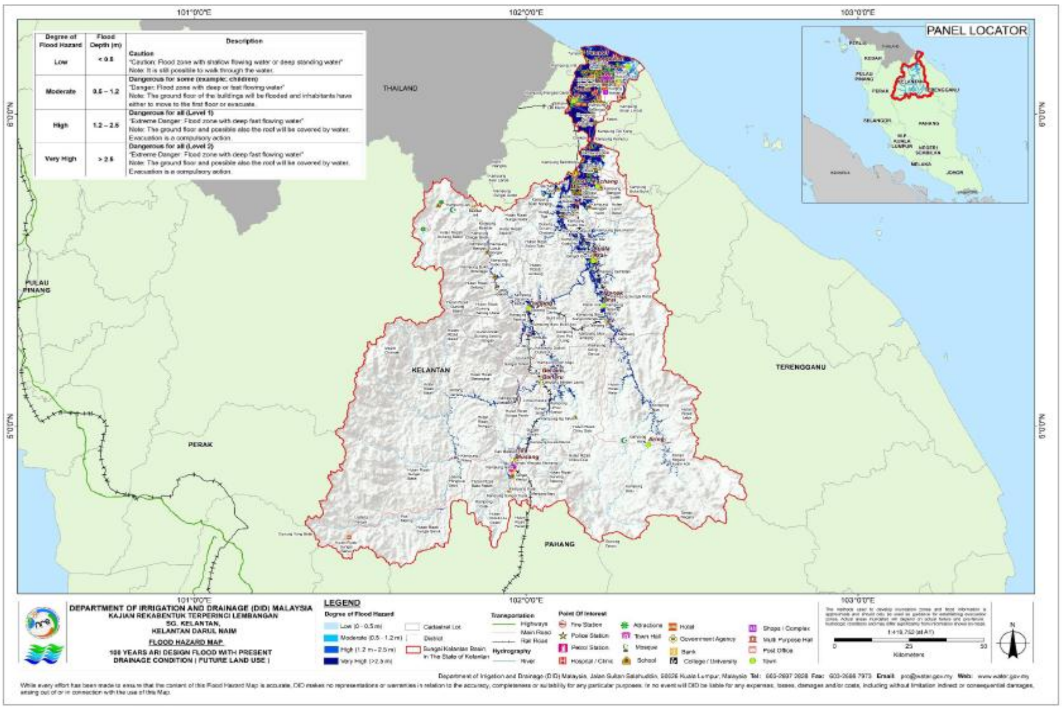

Figure 2: Flood Hazard Map for 100 Years ARI 100 Years ARI Design Flood with Present Drainage Condition (Future Land Use)

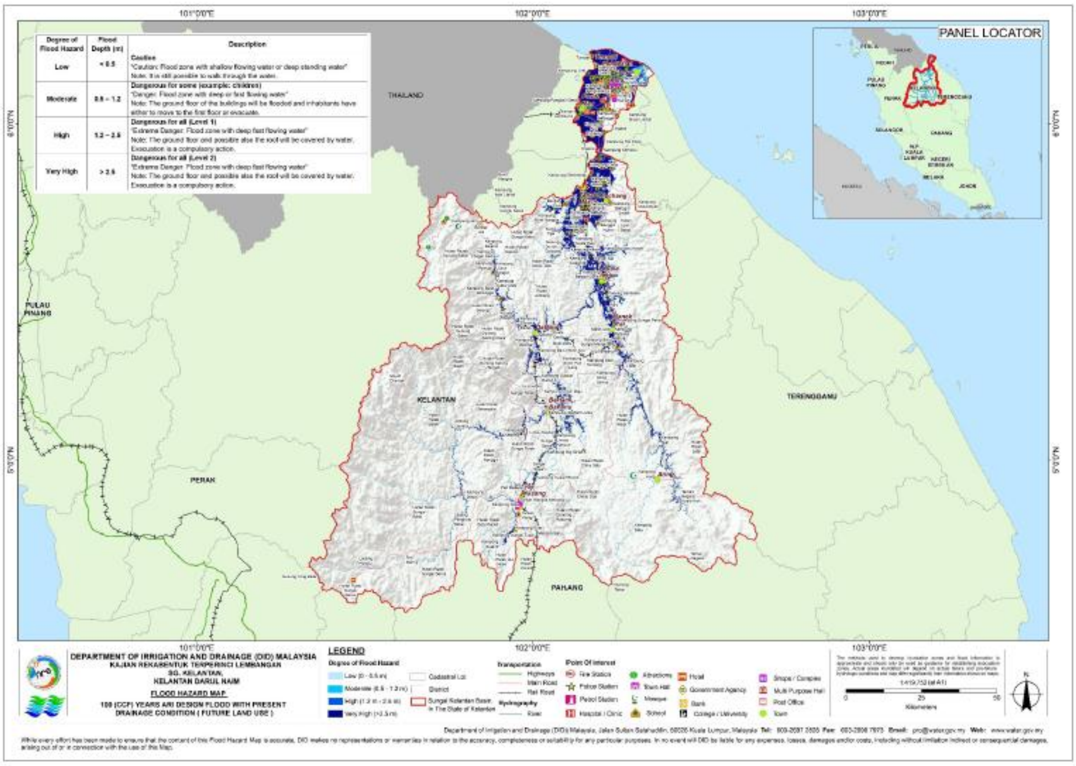

Figure 3: Flood Hazard Map for 100 Years ARI + Climate Change Factor (CCF) Design Flood with Present Drainage Condition (Future Land Use)

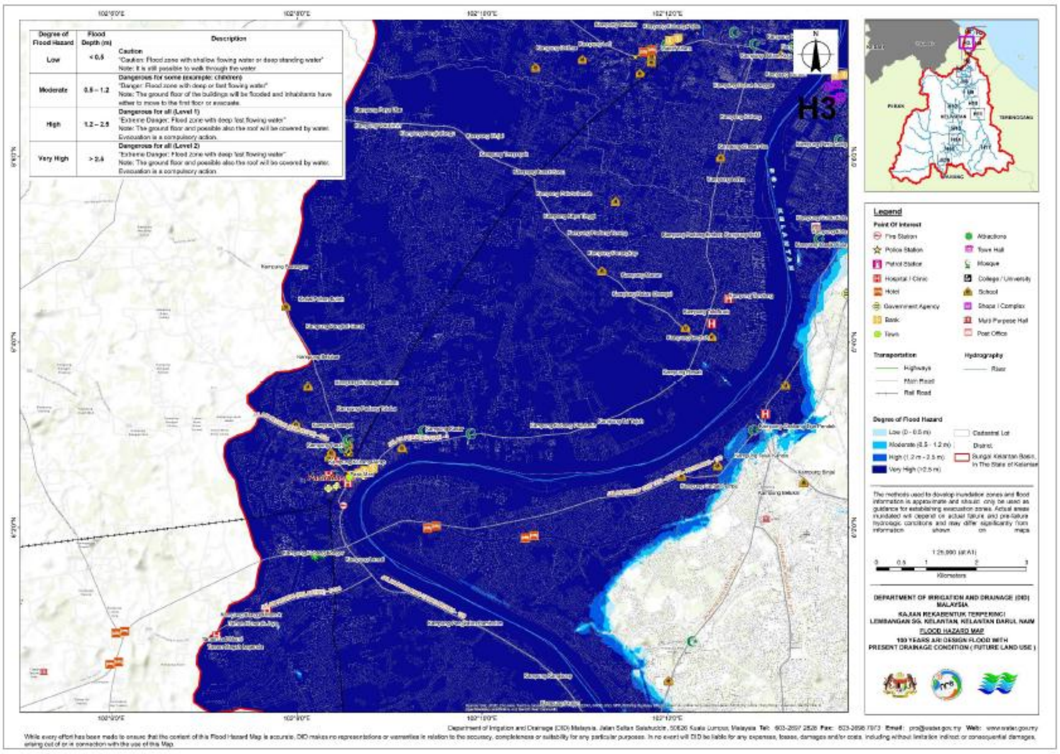

Figure 4: 100 Years ARI Design Flood with Present Drainage Condition (Future Land Use) at H3 Grid location

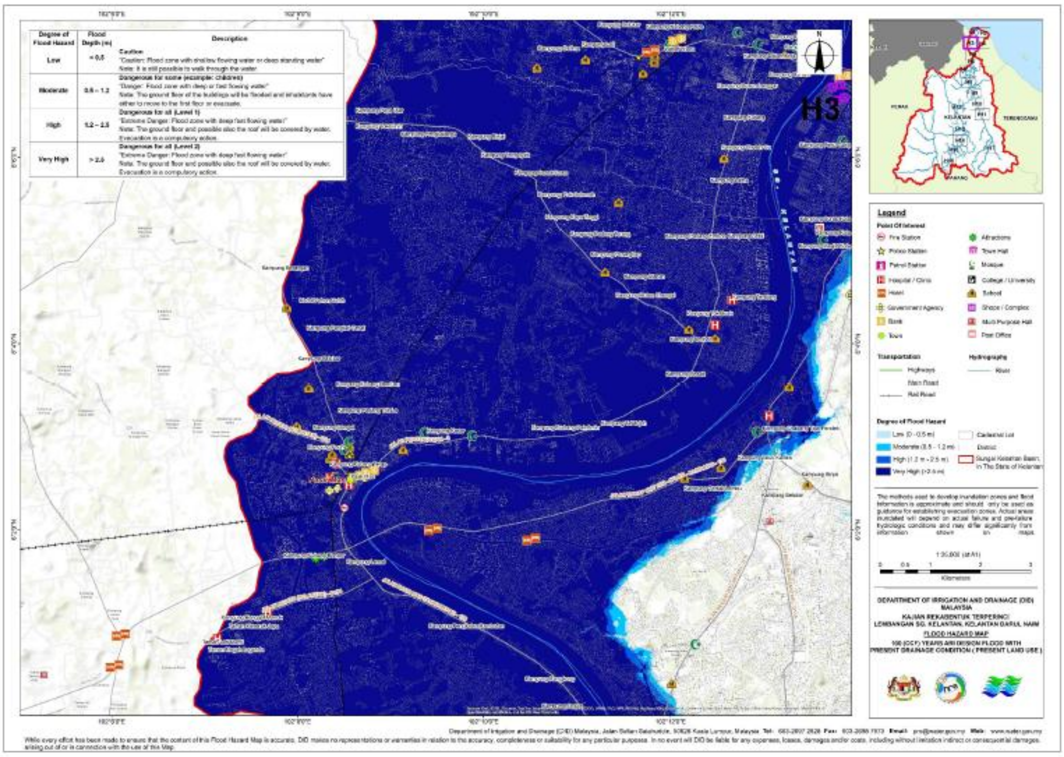

Figure 5: Flood Hazard Map for 100 Years ARI + Climate Change Factor (CCF) Design Flood with Present Drainage Condition (Present Land Use) at H3 Grid Location

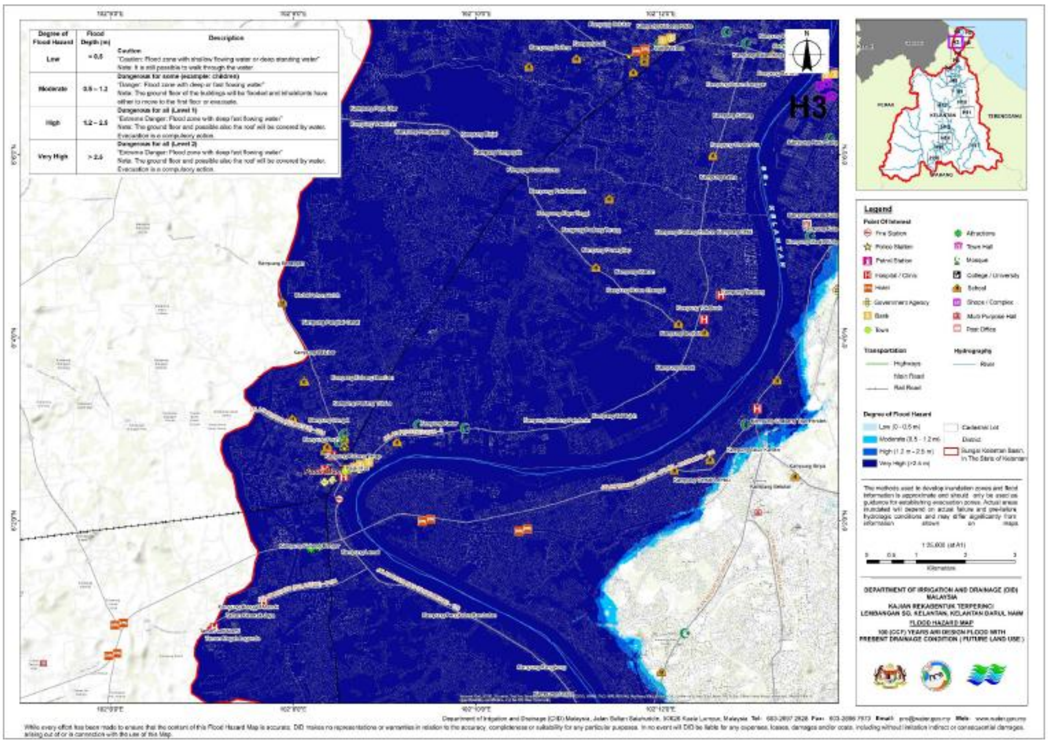

Figure 6: Flood Hazard Map for 100 Years ARI + Climate Change Factor (CCF) Design Flood with Present Drainage Condition (Future Land Use) at H3 Grid Location

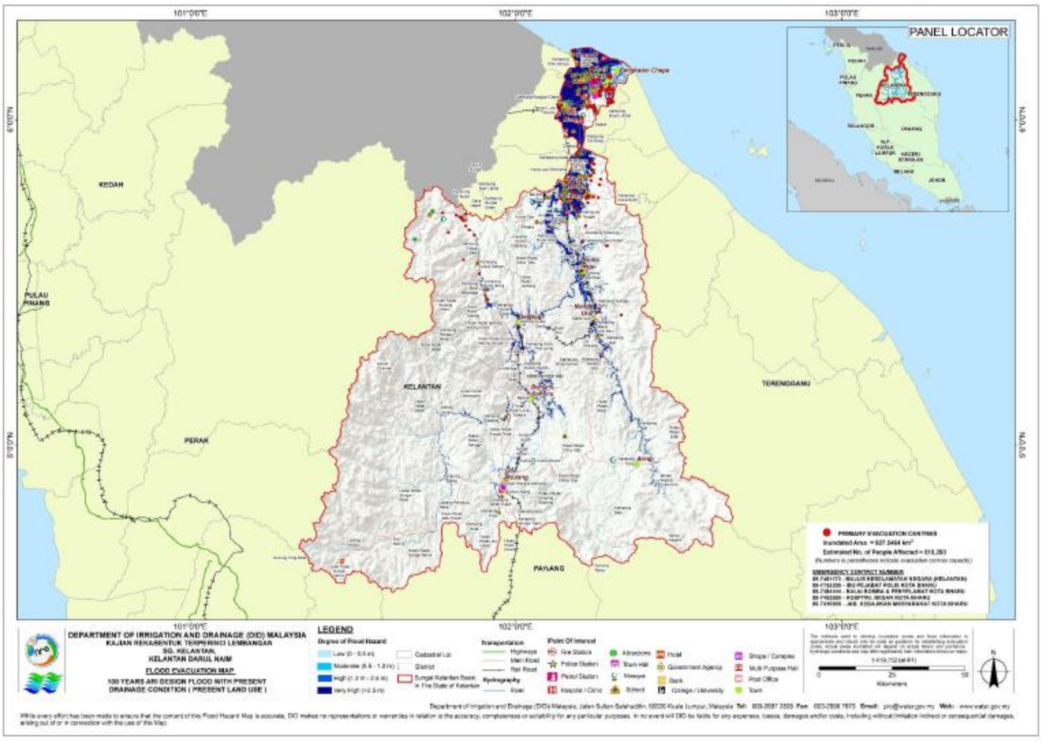

Figure 6: Flood Evacuation Map for 100 Years ARI Design Flood with Present Drainage Condition (Present Land Use)

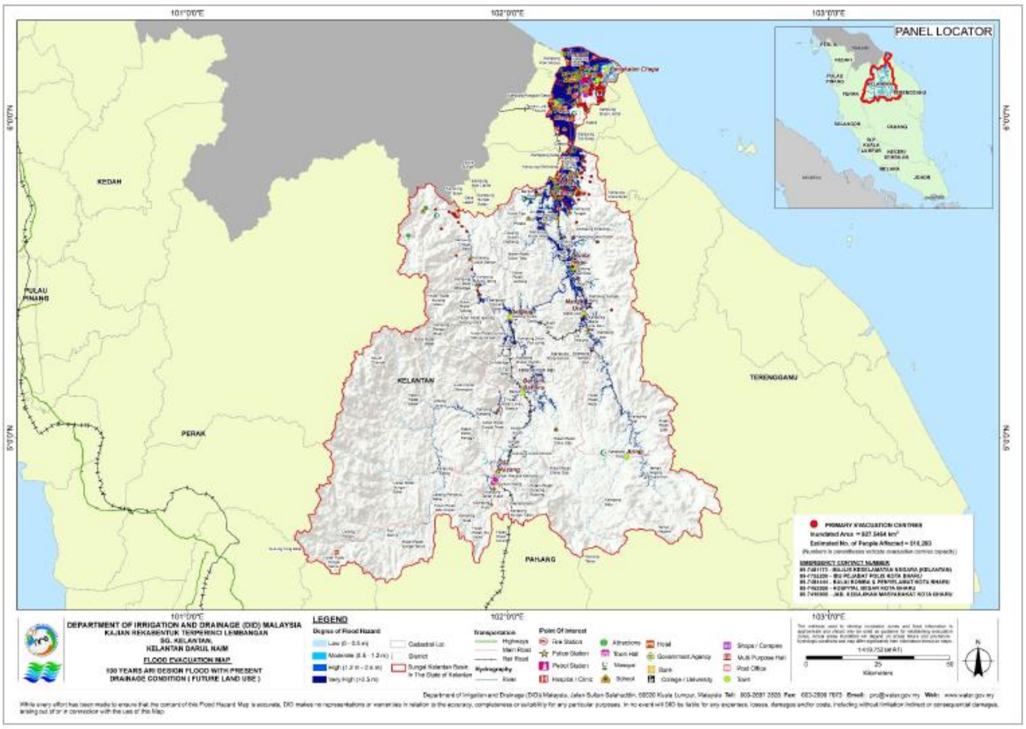

Figure 7: Flood Evacuation Map for 100 Years ARI Design Flood with Present Drainage Condition (Future Land Use)

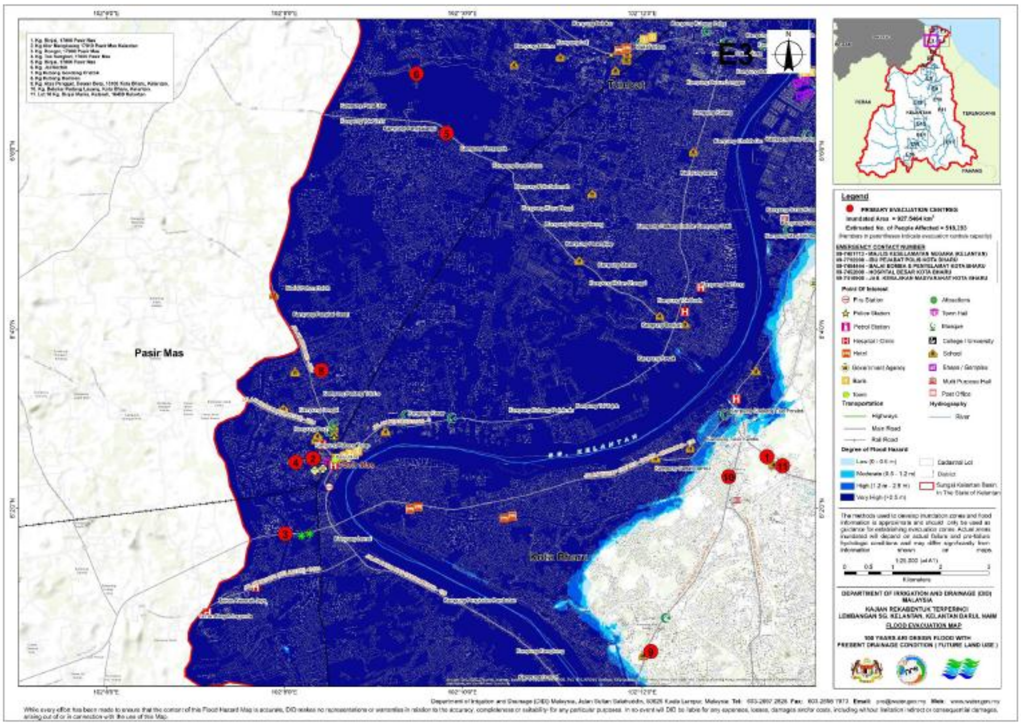

Figure 8: Flood Evacuation Map for 100 Years ARI Design Flood with Present Drainage Condition (Future Land Use) at E3 Grid Location

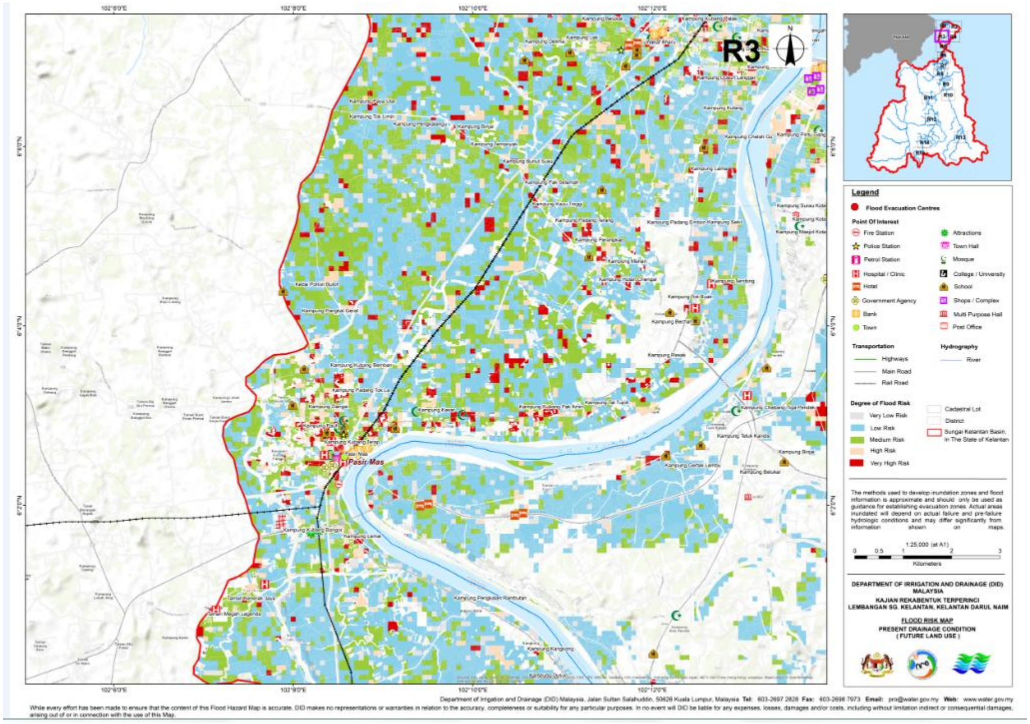

Figure 9: Flood Risk Map for 100 Years ARI Design Flood with Present Drainage Condition (Future Land Use) at R3 Grid Location.